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(54) Title:	METHOD AND APPARATUS FOR AUTHENTICATING AND DISCRIMINATING CURRENCY	
(57) Abstract	<p>A system for authenticating and discriminating currency utilizes an ultraviolet light source to illuminate a document to be tested and an ultraviolet light detector to detect the ultraviolet light reflected by the document. An output signal proportional to the reflected ultraviolet light is provided from the ultraviolet light detector to a signal processor, which determines the authenticity of the document based upon the output signal. The document is considered genuine if the output signal is within a predetermined range of the expected value. In another embodiment, the system includes an ultraviolet light source to illuminate a document to be tested and both an ultraviolet light detector and a visible light detector. The visible light detector detects and provides an output signal proportional to the visible light emitted by the document. The signal processor receives both the ultraviolet light detector and visible light detector output signals and determines the authenticity of the document based upon the reflected ultraviolet light and detected visible light. The document is considered genuine if the output signal is within a predetermined range of the expected value and if the amount of visible light does not exceed a visible light threshold.</p>	

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METHOD AND APPARATUS FOR AUTHENTICATING AND DISCRIMINATING CURRENCY

Field of the Invention

The present invention relates, in general, to currency authentication and discrimination. More specifically, the present invention relates to an apparatus and method for authenticating the genuineness of currency bills of different denominations
5 and discriminating said bills from counterfeit currency.

Background

A number of methods have been developed for authenticating the genuineness of security documents. These methods include sensing magnetic, optical, conductive, and other characteristics of documents under test. In general, it has been found that no single
10 authentication test is capable of detecting all types of counterfeit documents while at the same time not rejecting any genuine documents. Therefore, more than one test may be employed whereby a first test is used to detect certain types of counterfeits and additional tests are used to detect other types of counterfeits.

It has been known that the illumination of certain substances with ultraviolet light
15 causes the substances to fluoresce, that is, to emit visible light. Some documents employ fluorescent materials as a security feature to inhibit counterfeiting. Typically, these fluorescent security features comprise a marking which is visibly revealed when the document is illuminated with ultraviolet light. Previous methods have been developed to authenticate such documents by sensing the fluorescent light emitted by a document
20 illuminated by ultraviolet light and comparing the sensed fluorescent light to the fluorescent light emitted by genuine documents.

Other documents, such as United States and British currency, are manufactured from special paper designed not to fluoresce under ultraviolet light. Previously known authenticating methods for such documents have sensed for the emission of fluorescent
25 light under ultraviolet illumination and have rejected as counterfeit those documents emitting fluorescent light.

However, it has been found that the presently known ultraviolet authentication methods do not detect all types of counterfeits. For example, while many counterfeit

United States and British bills do emit fluorescent light under ultraviolet illumination, some counterfeit United States and British bills do not.

Summary Of The Invention

It is a principal object of the present invention to provide an improved method 5 and apparatus for authenticating and discriminating currency bills comprising a plurality of currency denominations.

It is another object of this invention to provide an improved method and apparatus of the above kind which is capable of efficiently discriminating among, authenticating, and counting bills of several currency denominations at a high speed and 10 with a high degree of accuracy.

It is another object of the present invention to provide an improved method and apparatus for authenticating documents which improves the ability of a system to accurately reject improper documents while reducing the likelihood of rejecting genuine documents.

- 15 The above objects may be achieved by one embodiment of the present invention in which currency bills are authenticated and discriminated by scanning a bill for first and second characteristic information, utilizing the first characteristic information to determine the denomination of a scanned bill, and using the second characteristic information to verify the genuineness of the bill. More particularly, a currency
20 evaluation device, according to the present invention, comprises detection circuitry for detecting first and second characteristic information from a scanned bill, a memory for storing sets of genuine first and second characteristic information for a plurality of denominations of genuine bills, and signal processing means for comparing the detected first and second characteristic information with the stored genuine first and second
25 characteristic information. The signal processing means performs a first comparison whereby the detected first characteristic information is compared with the stored sets of genuine first characteristic information. This first comparison results in either an indication of the denomination of the scanned bill or an error. The results of the first comparison are used to streamline a second comparison between detected and stored
30 second characteristic information. The second comparison compares the detected second characteristic information with stored genuine second characteristic information

corresponding to the denomination indicated by the first comparison. The second comparison results in either an indication of the genuineness of the scanned bill or an error.

One embodiment of the present invention is a method of detecting counterfeit currency that includes the steps of determining the denomination of the bill being evaluated, generating data corresponding to the concentration of magnetic ink on the bill and comparing this data to the expected concentration of magnetic ink on a genuine bill of the same denomination. The bill is considered genuine if the data is within an acceptable range of an expected value.

The apparatus for implementing the above method employs a microprocessor to control an optical scanning operation of a bill and to generate image data that is compared to stored images corresponding to genuine denominations of currency. The denomination of the bill is determined by evaluating the similarity between the image data and the stored images of at least seven denominations of United States currency (one dollar, two dollars, five dollars, ten dollars, twenty dollars, fifty dollars and one hundred dollars). The microprocessor also controls measurement of data corresponding to the concentration of magnetic ink on the bill and determines the genuineness of the bill by comparing the measured concentration of magnetic ink to the expected concentration for a bill of the same denomination. A signal indicative of whether the bill is genuine or counterfeit is generated by the microprocessor depending on whether the data is within a predetermined range of the expected value.

It is another object of the present invention to provide an improved method and apparatus for authenticating documents including United States and foreign currency bills by illuminating them with ultraviolet light and measuring the amount of ultraviolet light which is reflected off the document. Based on the amount of ultraviolet light which is detected, the document is either authenticated or rejected.

In one embodiment of the present invention, the document is authenticated if the amount of reflected ultraviolet light exceeds a minimum UV threshold value and does not exceed a maximum UV threshold value, e.g. within an acceptable range of values defined between a minimum UV threshold value and a maximum UV threshold value.

The document is rejected if the amount of reflected ultraviolet light is not within the acceptable range of values.

It is another object of the present invention to provide an improved method and apparatus for authenticating documents including United States and foreign currency

- 5 bills by illuminating them with ultraviolet light and measuring both the amount of reflected ultraviolet light and the amount of emitted visible light. Based on the amount of ultraviolet light detected and the amount of visible light detected, a document is either authenticated or rejected.

- In another embodiment of the present invention, a bill is authenticated if the
10 amount of visible light detected is below a visible light threshold value and the amount of reflected ultraviolet light exceeds a minimum UV threshold value and does not exceed a maximum UV threshold value, e.g. within an acceptable range of values defined between a minimum UV threshold value and a maximum UV threshold value. The bill is rejected if the amount of visible light detected is above the visible light threshold value or if the
15 amount of reflected ultraviolet light is not within the acceptable range of values.

- The above described embodiments may be adapted to authenticate other types of documents such as food stamps and checks, or may be adapted to authenticate other types of currency bills. For instance, some genuine documents may be designed to reflect ultraviolet light only in certain locations and/or in a predetermined pattern. An
20 alternative embodiment of the present invention may be designed to accept documents which exhibit similar characteristics while rejecting those which do not. Likewise, an alternative embodiment of the present invention may be employed to authenticate documents based on both their characteristics with respect to reflected ultraviolet light and their characteristics with respect to fluorescent emissions, e.g., detecting the amount, location, and/or pattern of fluorescent emissions.
25

Brief Description Of The Drawings

Other objects and advantages of the invention will become apparent upon reading the following detailed description in conjunction with the drawings in which:

- FIG. 1 is a block diagram of one embodiment of a system for detecting
30 counterfeit currency according to the present invention;

FIG. 2 is a flow diagram that illustrates the operation of the counterfeit detector of the present invention;

FIG. 3 is a graphical representation of the magnetic data points generated by both a genuine one hundred dollar bill and a counterfeit one hundred dollar bill;

5 FIG. 4 is a functional block diagram illustrating a currency discriminating and authenticating system according to the present invention;

FIG. 5a is a diagrammatic perspective illustration of the successive areas scanned during the traversing movement of a single bill across an optical sensor in the system of FIG. 4;

10 FIG. 5b is a perspective view of a bill and a preferred area to be optically scanned on the bill;

FIG. 5c is a diagrammatic side elevation of the scan area to be optically scanned on a bill;

15 FIGs. 6a and 6b comprise a flowchart illustrating the sequence of operations involved in implementing the discrimination and authentication system of FIG. 4;

FIG. 7 is a flowchart illustrating the sequence of operations involved in implementing the detection of double or overlapping bills in the system of FIG. 4;

FIG. 8a is a side view of a preferred embodiment of a document authenticating system according to the present invention;

20 FIG. 8b is a top view of the preferred embodiment of FIG. 8a along the direction 8b;

FIG. 8c is a top view of the preferred embodiment of FIG. 8a along the direction 8c; and

25 FIG. 9 is a functional block diagram illustrating a preferred embodiment of a document authenticating system according to the present invention.

Detailed Description Of The Preferred Embodiments

Referring to the drawings, FIG. 1 shows a block diagram of a counterfeit detector 10. A microprocessor 12 controls the overall operation of the counterfeit detector 10. It should be noted that the detailed construction of a mechanism to convey bills through the

30 counterfeit detector 10 is not related to the practice of the present invention. Many configurations are well-known in the prior art. An exemplary configuration includes an

arrangement of pulleys and rubber belts driven by a single motor. An encoder 14 may be used to provide input to the microprocessor 12 based on the position of a drive shaft 16, which operates the bill-conveying mechanism. The input from the encoder 14 allows the microprocessor to calculate the position of a bill as it travels and to determine the timing
5 of the operations of the counterfeit detector 10.

A stack of currency (not shown) may be deposited in a hopper 18 which holds the currency securely and allows the bills in the stack to be conveyed one at a time through the counterfeit detector 10. After the bills are conveyed to the interior of the counterfeit detector 10, a portion of the bill is optically scanned by an optical sensor 20 of the type
10 commonly known in the art. The optical sensor generates signals that correspond to the amount of light reflected by a small portion of the bill. Signals from the optical sensor 20 are sent to an amplifier circuit 22, which, in turn, sends an output to an analog-to-digital convertor 24. The output of the ADC is read by the microprocessor 12. The microprocessor 12 stores each element of data from the optical sensor 20 in a range of
15 memory locations in a random access memory ("RAM") 26, forming a set of image data that corresponds to the object scanned.

As the bill continues its travel through the counterfeit detector 10, it is passed adjacent to a magnetic sensor 28, which detects the presence of magnetic ink. The magnetic sensor 28 desirably makes a plurality of measurements along a path parallel to
20 one edge of the bill being examined. For example, the path sensed by the magnetic sensor 28 may be parallel to the shorter edges of the bill and substantially through the bill's center. The output signal from the magnetic sensor 28 is amplified by an amplifier circuit 30 and digitized by the ADC 24. The digital value of each data point measured by the magnetic sensor 28 is read by the microprocessor 12, whereupon it is stored in a
25 range of memory in the RAM 26.

The digitized magnetic data may be mathematically manipulated to simplify its use. For example, the value of all data points may be summed to yield a checksum, which may be used for subsequent comparison to expected values computed from samples of genuine bills. As will be apparent, calculation of a checksum for later
30 comparison eliminates the need to account for the orientation of the bill with respect to the magnetic sensor 28. This is true because the checksum represents the concentration

of magnetic ink across the entire path scanned by the magnetic sensor 28, regardless of variations caused by higher concentrations in certain regions of the bill.

- The image data stored in the RAM 26 is compared by the microprocessor 12 to standard image data stored in a read only memory ("ROM") 32. The stored image data
- 5 corresponds to optical data generated from genuine currency of a plurality of denominations. The ROM image data may represent various orientations of genuine currency to account for the possibility of a bill in the stack being in a reversed orientation compared to other bills in the stack. If the image data generated by the bill being evaluated does not fall within an acceptable limit of any of the images stored in ROM,
- 10 the bill is determined to be of an unknown denomination. The machine stops to allow removal of the document from the stack of currency.

- If the image data from the bill being evaluated corresponds to one of the images stored in the ROM 32, the microprocessor 12 compares the checksum of the magnetic data to one of a plurality of expected checksum values stored in the ROM 32. An
- 15 expected checksum value is stored for each denomination that is being counted. The value of each expected checksum is determined, for example, by averaging the magnetic data from a number of genuine samples of each denomination of interest. If the value of the measured checksum is within a predetermined range of the expected checksum, the bill is considered to be genuine. If the checksum is not within the acceptable range, the
- 20 operator is signalled that the document is suspect and the operation of the counterfeit detector 10 is stopped to allow its retrieval.

- If the bill passes both the optical evaluation and the magnetic evaluation, it exits the counterfeit detector 10 to a stacker 34. Furthermore, the counterfeit detector 10 may desirably include the capability to maintain a running total of genuine currency of each
- 25 denomination.

- It should be noted that the magnetic checksum is only compared to the expected checksum for a single denomination (i.e. the denomination that the optical data comparison has indicated). Thus, the only way in which a bill can be classified as genuine is if its magnetic checksum is within an acceptable range for its specific
- 30 denomination. For a counterfeit bill to be considered genuine by the counterfeit detector of the present invention, it would have to be within an acceptable range in the

denomination-discriminating optical comparison and have a distribution of magnetic ink within an acceptable range for its specific denomination.

To summarize the operation of the system, a stack of bills is fed into the hopper 18. Each bill is transported adjacent to the optical sensor 20, which generates image data 5 corresponding to one side of the bill. The bill is also scanned by a magnetic sensor 28 and a plurality of data points corresponding to the presence of magnetic ink are recorded by the microprocessor 12. A checksum is generated by adding the total of all magnetic data points. The image data generated by the optical sensor 20 is compared to stored images that correspond to a plurality of denominations of currency. When the 10 denomination of the bill being evaluated has been determined, the checksum is compared to a stored checksum corresponding to a genuine bill of that denomination. The microprocessor 12 generates a signal indicating that the bill is genuine or counterfeit depending on whether said data is within a predetermined range of the expected value. Bills exit the counterfeit detector 10 and are accumulated in the stacker 34.

15 FIG. 2 is a flow diagram of an exemplary system embodying the present invention. At step 36, the presence of a bill approaching the optical sensor 20 is detected by the microprocessor 12, which initiates an optical scanning operation 38. Image data generated by the optical scanning operation are stored in RAM 26. The number of optical samples taken is not critical to the operation of the present invention, but the 20 probability of accurate classification of the denomination of a bill increases as the number of samples increases.

At step 40, the microprocessor 12 initiates the magnetic scanning operation. The data points obtained by the magnetic scanning operation may be stored in the RAM 26 and added together later to yield a checksum, as shown in step 44. Alternatively, the 25 checksum may be calculated by keeping a running total of the magnetic data values by adding each newly acquired value to the previous total. As with the optical scanning operation, the number of data points measured is not essential, but the chances of accurately identifying a counterfeit bill based on the concentration of magnetic ink improve as the number of samples increases. At step 42, the microprocessor determines 30 the denomination of the bill by comparing the image data to a plurality of known images, each of which corresponds to a specific denomination of currency. The bill is identified

as belonging to the denomination corresponding to one of the known scan patterns if the correlation between the two is within an acceptable range. At step 46, the checksum resulting from the summation of the magnetic data points is compared to an expected value for a genuine bill of the denomination identified by the comparison of the image data to the stored data.

The expected value may be determined in a variety of ways. One method is to empirically measure the concentration of magnetic ink on a sample of genuine bills and average the measured concentrations. Another method is to program the microprocessor to periodically update the expected value based on magnetic data measurements of bills evaluated by the counterfeit detector over a period of time.

If the checksum of the bill being evaluated is within a predetermined range of the expected value, the bill is considered to be genuine. Otherwise, the bill is considered to be counterfeit. As will be apparent, the choice of an acceptable variation from the expected checksum determines the sensitivity of the counterfeit detector. If the range chosen is too narrow, the possibility that a genuine bill will be classified as counterfeit is increased. On the other hand, the possibility that a counterfeit bill will be classified as genuine increases if the acceptable range is too broad.

FIG. 3 is a graphical representation of the magnetic data points generated by both a genuine one hundred dollar bill (solid line) and a counterfeit one hundred dollar bill (broken line). As previously noted, bills are desirably scanned along a path that is parallel to one of their short edges. The graph shown in FIG. 3 shows magnetic data obtained by scanning a path passing approximately through the center of the bill. The measurements in the region designated "a" correspond to the area at the top of the bill. The area designated "b" corresponds to the central region of the bill and the region designated "c" corresponds to the bottom of the bill. The magnetic measurements for the genuine bill are relatively high in region a because of the high concentration of magnetic ink near the top of the bill. The concentration of magnetic ink in region b is relatively small and the concentration in region c is generally between the concentrations in regions a and c.

It should be noted that the concentration of magnetic ink in a typical counterfeit bill is uniformly low. Thus, the sum of all the data points for a counterfeit bill is

generally significantly lower than for a genuine bill. Nonetheless, as counterfeiting techniques become more sophisticated, the correlation between genuine bills and counterfeits has improved.

- The system described above increases the chances of identifying a counterfeit bill
- 5 because the denomination of a bill being evaluated is determined prior to the evaluation of the bill for genuineness. The checksum of the bill being evaluated is only compared to the expected checksum for a bill of that denomination. The process of identifying the denomination of the bill prior to evaluating it for genuineness minimizes the chance that a "good" counterfeit will generate a checksum indicative of a genuine bill of any
- 10 denomination.

Referring next to FIG. 4, there is shown a functional block diagram illustrating a preferred embodiment of a currency discriminating and authenticating system 50 which includes a bill accepting station 52 where stacks of currency bills that need to be identified, authenticated, and counted are positioned. Accepted bills are acted upon by a

15 bill separating station 54 which functions to pick out or separate one bill at a time for being sequentially relayed by a bill transport mechanism 56, according to a precisely predetermined transport path, across two scanheads 60 and 62 where the currency denomination of the bill is identified and the genuineness of the bill is authenticated. In the preferred embodiment depicted, the scanhead 60 is an optical scanhead that scans for

20 a first type of characteristic information from a scanned bill 57 which is used to identify the bill's denomination. The second scanhead 62 scans for a second type of characteristic information from the scanned bill 57. While in the illustrated preferred embodiment scanheads 60 and 62 are separate and distinct, it is understood that these may be incorporated into a single scanhead. For example, where the first characteristic sensed is

25 intensity of reflected light and the second characteristic sensed is color, a single optical scanhead having a plurality of detectors, one or more without filters and one or more with colored filters, may be employed (U.S. Pat. No. 4,992, 860 incorporated herein by reference). The scanned bill is then transported to a bill stacking station 64 where bills so processed are stacked for subsequent removal.

30 The optical scanhead 60 of the preferred embodiment depicted in FIG. 4 comprises at least one light source 66 directing a beam of coherent light downwardly

onto the bill transport path so as to illuminate a substantially rectangular light strip 58 upon a currency bill 57 positioned on the transport path below the scanhead 60. Light reflected off the illuminated strip 58 is sensed by a photodetector 68 positioned directly above the strip. The analog output of the photodetector 68 is converted into a digital signal by means of an analog-to-digital (ADC) convertor unit 70 whose output is fed as a digital input to a central processing unit (CPU) 72.

The second scanhead 62 comprises at least one detector 74 for sensing a second type of characteristic information from a bill. The analog output of the detector 74 is converted into a digital signal by means of a second analog to digital converter 76 whose 10 output is also fed as a digital input to the central processing unit (CPU) 72.

While scanhead 60 in the preferred embodiment of FIG. 4 is an optical scanhead, it should be understood that the first and second scanheads 60 and 62 may be designed to detect a variety of characteristic information from currency bills. Additionally these scanheads may employ a variety of detection means such as magnetic or optical sensors. 15 For example, a variety of currency characteristics can be measured using magnetic sensing. These include detection of patterns of changes in magnetic flux (U.S. Pat. No. 3,280,974), patterns of vertical grid lines in the portrait area of bills (U.S. Pat. No. 3,870,629), the presence of a security thread (U.S. Pat. No. 5,151,607), total amount of magnetizable material of a bill (U.S. Pat. No. 4,617,458), patterns from sensing the 20 strength of magnetic fields along a bill (U.S. Pat. No. 4,593,184), and other patterns and counts from scanning different portions of the bill such as the area in which the denomination is written out (U.S. Pat. No. 4,356,473).

With regard to optical sensing, a variety of currency characteristics can be measured such as detection of density (U.S. Pat. No. 4,381,447), color (U.S. Pat. Nos. 25 4,490,846; 3,496,370; 3,480,785), length and thickness (U.S. Pat. No. 4,255,651), the presence of a security thread (U.S. Pat. No. 5,151,607) and holes (U.S. Pat. No. 4,381,447), and other patterns of reflectance and transmission (U.S. Pat. No. 3,496,370; 3,679,314; 3,870,629; 4,179,685). Color detection techniques may employ color filters, colored lamps, and/or dichroic beamsplitters (U.S. Pat. Nos. 4,841,358; 4,658,289; 30 4,716,456; 4,825,246, 4,992,860 and EP 325,364). An optical sensing system using ultraviolet light is described in the assignee's copending U.S. patent application Serial

No. 08/317,349, filed October 4, 1994, and incorporated herein by reference, and described below.

In addition to magnetic and optical sensing, other techniques of detecting characteristic information of currency include electrical conductivity sensing, capacitive sensing (U.S. Pat. No. 5,122,754 [watermark, security thread]; 3,764,899 [thickness]; 3,815,021 [dielectric properties]; 5,151,607 [security thread]), and mechanical sensing (U.S. Pat. No. 4,381,447 [limpness]; 4,255,651 [thickness]).

Referring again to FIG. 4, the bill transport path is defined in such a way that the transport mechanism 56 moves currency bills with the narrow dimension of the bills parallel to the transport path and the scan direction. Alternatively, the system 50 may be designed to scan bills along their long dimension or along a skewed dimension. As a bill 57 moves on the transport path on the scanhead 60, the coherent light strip 58 effectively scans the bill across the narrow dimension of the bill. In the preferred embodiment depicted, the transport path is so arranged that a currency bill 57 is scanned by scanhead 60 approximately about the central section of the bill along its narrow dimension, as best shown in FIG. 4. The scanhead 60 functions to detect light reflected from the bill as it moves across the illuminated light strip 58 and to provide an analog representation of the variation in light so reflected which, in turn, represents the variation in the dark and light content of the printed pattern or indicia on the surface of the bill. This variation in light reflected from the narrow dimension scanning of the bills serves as a measure for distinguishing, with a high degree of confidence, among a plurality of currency denominations which the system of this invention is programmed to handle.

A series of such detected reflectance signals are obtained across the narrow dimension of the bill, or across a selected segment thereof, and the resulting analog signals are digitized under control of the CPU 72 to yield a fixed number of digital reflectance data samples. The data samples are then subjected to a digitizing process which includes a normalizing routine for processing the sampled data for improved correlation and for smoothing out variations due to "contrast" fluctuations in the printed pattern existing on the bill surface. The normalized reflectance data so digitized represents a characteristic pattern that is fairly unique for a given bill denomination and provides sufficient distinguishing features between characteristic patterns for different

currency denominations. This process is more fully explained in United States patent application Serial No. 07/885,648, filed on May 19, 1992, now issued as United States Patent No. 5,295,196 for "Method and Apparatus for Currency Discrimination and Counting," which is incorporated herein by reference in its entirety.

- 5 In order to ensure strict correspondence between reflectance samples obtained by narrow dimension scanning of successive bills, the initiation of the reflectance sampling process is preferably controlled through the CPU 72 by means of an optical encoder 78 which is linked to the bill transport mechanism 56 and precisely tracks the physical movement of the bill 57 across the scanheads 60 and 62. More specifically, the optical
10 encoder 78 is linked to the rotary motion of the drive motor which generates the movement imparted to the bill as it is relayed along the transport path. In addition, the mechanics of the feed mechanism (not shown, see United States Patent No. 5,295,196 referred to above) ensure that positive contact is maintained between the bill and the transport path, particularly when the bill is being scanned by scanheads 60 and 62.
15 Under these conditions, the optical encoder 78 is capable of precisely tracking the movement of the bill 57 relative to the light strip 58 generated by the scanhead 60 by monitoring the rotary motion of the drive motor.

The output of photodetector 68 is monitored by the CPU 72 to initially detect the presence of the bill underneath the scanhead 60 and, subsequently, to detect the starting
20 point of the printed pattern on the bill, as represented by the thin borderline 57a which typically encloses the printed indicia on currency bills. Once the borderline 57a has been detected, the optical encoder 78 is used to control the timing and number of reflectance samples that are obtained from the output of the photodetector 68 as the bill 57 moves across the scanhead 60 and is scanned along its narrow dimension.

- 25 The detection of the borderline 57a serves as an absolute reference point for initiation of sampling. If the edge of a bill were to be used as a reference point, relative displacement of sampling points can occur because of the random manner in which the distance from the edge to the borderline 57a varies from bill to bill due to the relatively large range of tolerances permitted during printing and cutting of currency bills. As a
30 result, it becomes difficult to establish direct correspondence between sample points in successive bill scans and the discrimination efficiency is adversely affected.

The use of the optical encoder 78 for controlling the sampling process relative to the physical movement of a bill 57 across the scanhead 60 is also advantageous in that the encoder 78 can be used to provide a predetermined delay following detection of the borderline prior to initiation of samples. The encoder delay can be adjusted in such a 5 way that the bill 57 is scanned only across those segments along its narrow dimension which contain the most distinguishable printed indicia relative to the different currency denominations.

It has been determined that the central, approximately two-inch portion of currency bills, as scanned across the central section of the narrow dimension of the bill, 10 provides sufficient data for distinguishing among various currency denominations of both United States and foreign currency on the basis of the correlation technique disclosed in United States Patent No. 5,295,196 referred to above. Accordingly, the optical encoder can be used to control the scanning process so that reflectance samples are taken for a set period of time and only after a certain period of time has elapsed since the borderline 57a 15 has been detected, thereby restricting the scanning to the desired central portion of the narrow dimension of the bill.

FIGs. 5a-5c illustrate the scanning process of scanhead 60 in more detail. Referring to FIG. 5b, as a bill 57 is advanced in a direction parallel to the narrow edges of the bill, scanning via a wide slit in the scanhead 60 is effected along a segment S of 20 the central portion of the bill 57. This segment S begins a fixed distance D inboard of the border line 57a. As the bill 57 traverses the scanhead 60, a strip s of the segment S is always illuminated, and the photodetector 68 produces a continuous output signal which is proportional to the intensity of the light reflected from the illuminated strip s at any given instant. This output is sampled at intervals controlled by the encoder, so that the 25 sampling intervals are precisely synchronized with the movement of the bill across the scanhead 60.

As illustrated in FIGS. 5a and 5c, it is preferred that the sampling intervals be selected so that the strips s that are illuminated for successive samples overlap one another. The odd-numbered and even-numbered sample strips have been separated in 30 FIGS. 5a and 5c to more clearly illustrate this overlap. For example, the first and second strips s1 and s2 overlap each other, the second and third strips s2 and s3 overlap each

other, and so on. Each adjacent pair of strips overlap each other. In the illustrative example, this is accomplished by sampling strips that are 0.050 inch wide at 0.029 inch intervals, along a segment S that is 1.83 inch long (64 samples).

- The optical sensing and correlation technique is based upon using the above
- 5 process to generate a series of stored intensity signal patterns using genuine bills for each denomination of currency that is to be detected. According to a preferred embodiment, two or four sets of stored intensity signal samples are generated and stored within system memory, preferably in the form of an EPROM 80 (see FIG. 4), for each detectable currency denomination. The sets of stored intensity signal samples for each bill are
- 10 generated from optical scans, performed on the green surface of the bill and taken along both the "forward" and "reverse" directions relative to the pattern printed on the bill. Alternatively, the optical scanning may be performed on the black side of U.S. currency bills or on either surface of foreign bills.

In adapting this technique to U.S. currency, for example, sets of stored intensity

15 signal samples are generated and stored for seven different denominations of U.S. currency, i.e., \$1, \$2, \$5, \$10, \$20, \$50 and \$100. More specifically, four sets of stored intensity signal samples are generated for the \$10 bill and the \$2 bill, and two sets of stored intensity signal samples are generated for each of the other denominations.

Accordingly, a master set of 18 different sets of stored intensity signal samples is stored

20 within the system memory for subsequent correlation purposes. Once the master set has been stored, the scanned first characteristic information, in this example being reflected light intensity signal samples, generated by scanning a bill under test is compared by the CPU 72 with each of the 18 sets of stored intensity signal samples to generate, for each comparison, a correlation number representing the extent of correlation, i.e., similarity

25 between corresponding ones of the plurality of data samples, for the sets of data being compared.

The CPU 72 is programmed to identify the denomination of the scanned bill as

corresponding to the set of stored intensity signal samples for which the correlation

number resulting from pattern comparison is found to be the highest. In order to

30 preclude the possibility of mischaracterizing the denomination of a scanned bill, as well as to reduce the possibility of spurious notes being identified as belonging to a valid

denomination, a bi-level threshold of correlation is used as the basis for making a "positive" call. Such a method is disclosed in United States Patent No. 5,295,196 referred to above.

- As a result of the first comparison described above based on the reflected light
- 5 intensity information retrieved by scanhead 60, the CPU 72 will have either determined the denomination of the scanned bill 57 or determined that the first scanned signal samples fail to sufficiently correlate with any of the sets of stored intensity signal samples in which case an error is generated. Provided that an error has not been generated as a result of this first comparison based on reflected light intensity
- 10 characteristics, a second comparison is performed. This second comparison is performed based on a second type of characteristic information, such as alternate reflected light properties, similar reflected light properties at alternate locations of a bill, light transmissivity properties, various magnetic properties of a bill, the presence of a security thread embedded within a bill, the color of a bill, the thickness or other dimension of a
- 15 bill, etc. The second type of characteristic information is retrieved from a scanned bill by the second scanhead 62. The scanning and processing by scanhead 62 may be controlled in a manner similar to that described above with regard to scanhead 60.

In addition to the sets of stored first characteristic information, in this example stored intensity signal samples, the EPROM 80 stores sets of stored second characteristic

20 information for genuine bills of the different denominations which the system 50 is capable of handling. Based on the denomination indicated by the first comparison, the CPU 72 retrieves the set or sets of stored second characteristic data for a genuine bill of the denomination so indicated and compares the retrieved information with the scanned second characteristic information. If sufficient correlation exists between the retrieved

25 information and the scanned information, the CPU 72 verifies the genuineness of the scanned bill 57. Otherwise, the CPU generates an error. While the embodiment illustrated in FIG. 4 depicts a single CPU 72 for making comparisons of first and second characteristic information and a single EPROM 80 for storing first and second characteristic information, it is understood that two or more CPUs and/or EPROMs

30 could be used, including one CPU for making first characteristic information

comparisons and a second CPU for making second characteristic information comparisons.

- Using the above sensing and correlation approach, the CPU 72 is programmed to count the number of bills belonging to a particular currency denomination whose 5 genuineness has been verified as part of a given set of bills that have been scanned for a given scan batch, and to determine the aggregate total of the currency amount represented by the bills scanned during a scan batch. The CPU 72 is also linked to an output unit 82 which is adapted to provide a display of the number of genuine bills counted, the breakdown of the bills in terms of currency denomination, and the aggregate total of the 10 currency value represented by counted bills. The output unit 82 can also be adapted to provide a print-out of the displayed information in a desired format.

- The interrelation between the use of the first and second type of characteristic information can be seen by considering FIGs. 6a and 6b which comprise a flowchart illustrating the sequence of operations involved in implementing a discrimination and 15 authentication system according to a preferred embodiment of the present invention. Upon the initiation of the sequence of operations (step 88), reflected light intensity information is retrieved from a bill being scanned (step 90). Similarly, second characteristic information is also retrieved from the bill being scanned (step 92). Denomination error and second characteristic error flags are cleared (steps 93 and 94). 20 Next the scanned intensity information is compared to each set of stored intensity information corresponding to genuine bills of all denominations the system is programmed to accommodate (step 98). For each denomination, a correlation number is calculated. The system then, based on the correlation numbers calculated, determines either the denomination of the scanned bill or generates a denomination error by setting 25 the denomination error flag (steps 100 and 102). In the case where the denomination error flag is set (step 102), the process is ended (step 112). Alternatively, if based on this first comparison, the system is able to determine the denomination of the scanned bill, the system proceeds to compare the scanned second characteristic information with the stored second characteristic information corresponding to the denomination determined 30 by the first comparison (step 104).

For example, if as a result of the first comparison the scanned bill is determined to be a \$20 bill, the scanned second characteristic information is compared to the stored second characteristic information corresponding to a genuine \$20 bill. In this manner, the system need not make comparisons with stored second characteristic information for

- 5 the other denominations the system is programmed to accommodate. If based on this second comparison (step 104) it is determined that the scanned second characteristic information does not sufficiently match that of the stored second characteristic information (step 106), then a second characteristic error is generated by setting the second characteristic error flag (step 108) and the process is ended (step 112). If the
- 10 second comparison results in a sufficient match between the scanned and stored second characteristic information (step 106), then the denomination of the scanned bill is indicated (step 110) and the process is ended (step 112).

Table 1

<u>Sensitivity</u> Denomination	1	2	3	4	5
\$1	200	250	300	375	450
\$2	100	125	150	225	300
\$5	200	250	300	350	400
\$10	100	125	150	200	250
\$20	120	150	180	270	360
\$50	200	250	300	375	450
\$100	100	125	150	250	350

- 15 An example of an interrelationship between authentication based on a first and second characteristic can be seen by considering Table 1. Table 1 depicts relative total magnetic content minimum thresholds for various denominations of genuine bills. Columns 1-5 represent varying degrees of sensitivity selectable by a user of a device employing the present invention. The values in Table 1 are set based on the scanning of
- 20 genuine bills of varying denominations for total magnetic content and setting required

- minimum thresholds based on the degree of sensitivity selected. The information in Table 1 is based on the total magnetic content of a genuine \$1 being 1000. The following discussion is based on a sensitivity setting of 4. In this example it is assumed that magnetic content represents the second characteristic tested. If the comparison of 5 first characteristic information, such as reflected light intensity, from a scanned bill and stored information corresponding to genuine bills results in an indication that the scanned bill is a \$10 denomination, then the total magnetic content of the scanned bill is compared to the total magnetic content minimum threshold of a genuine \$10 bill, i.e., 200. If the magnetic content of the scanned bill is less than 200, the bill is rejected.
- 10 Otherwise it is accepted as a \$10 bill.

Alternatively, a table of threshold values may be prepared by scanning genuine bills of varying denominations for total magnetic content and setting both minimum and maximum total magnetic content thresholds for each sensitivity level. A bill under test is authenticated if its total magnetic content exceeds the minimum threshold and does not 15 exceed the maximum threshold, e.g. within an acceptable range of values defined between the minimum and maximum thresholds. Conversely, a bill under test is rejected if its total magnetic content is not within the acceptable range of values.

According to another feature of the present invention, the doubling or overlapping 20 of bills in the transport system is detected by the provision of a pair of optical sensors which are co-linearly disposed opposite to each other within the scan head area along a line that is perpendicular to the direction of bill flow, i.e., parallel to the edge of test bills along their wide dimensions as the bills are transported across the optical scan head. The pair of optical sensors S1 and S2 (not shown) are co-linearly disposed within the scan head area in close parallelism with the wide dimension edges of incoming test bills. In 25 effect, the optical sensors S1 and S2 (having corresponding light sources and photodetectors - not shown) are disposed opposite each other along a line within the scan head area which is perpendicular to the direction of bill flow. These sensors S1 and S2 serve as second detectors for detecting second characteristic information, namely density.

Although not illustrated in the drawings, it should be noted that corresponding 30 photodetectors (not shown) are provided within the scanhead area in immediate opposition to the corresponding light sources and underneath the flat section of the

transport path. These detectors detect the beam of coherent light directed downwardly onto the bill transport path from the light sources corresponding to the sensors S1 and S2 and generate an analog output which corresponds to the sensed light. Each such output is converted into a digital signal by a conventional ADC convertor unit (not shown) whose 5 output is fed as a digital input to and processed by the system CPU (not shown), in a manner similar to that indicated in the arrangement of FIG. 4.

The presence of a bill which passes under the sensors S1 and S2 causes a change in the intensity of the detected light, and the corresponding change in the analog output of the detectors serves as a convenient means for density-based measurements for 10 detecting the presence of "doubles" (two or more overlaid or overlapped bills) during the currency recognition and counting process. For instance, the sensors may be used to collect a predefined number of density measurements on a test bill, and the average density value for a bill may be compared to predetermined density thresholds (based, for instance, on standardized density readings for master bills) to determine the presence of 15 overlaid bills or doubles. The above sensors and doubles detection technique is described in more detail in United States Patent No. 5,295,196 which is incorporated herein by reference.

A routine for using the outputs of the two sensors S1 and S2 to detect any doubling or overlapping of bills is illustrated in FIG. 7. This routine uses a determination 20 of the denomination of a bill based on first characteristic information to streamline doubles detection wherein second characteristic information corresponds to the density of scanned bills. This routine starts when the denomination of a scanned bill has been determined via comparing first characteristic information at step 401, as described previously. To permit variations in the sensitivity of the density measurement, a "density 25 setting choice" is retrieved from memory at step 402. The operator makes this choice manually, according to whether the bills being scanned are new bills, requiring a higher degree of sensitivity, or used bills, requiring a lower level of sensitivity. After the "density setting choice" has been retrieved, the system then proceeds through a series of steps which establish a density comparison value according to the denomination of the 30 bill. Thus, step 403 determines whether the bill has been identified as a \$20-bill, and if the answer is affirmative, the \$20-bill density comparison value is retrieved from

memory at step 404. A negative answer at step 443 advances the system to step 405 to determine whether the bill has been identified as a \$100-bill, and if the answer is affirmative, the \$100-bill density comparison value is retrieved from memory at step 406.

A negative answer at step 405 advances the system to step 407 where a general density comparison value, for all remaining bill denominations, is retrieved from memory.

At step 408, the density comparison value retrieved at step 404, 406 or 407 is compared to the average density represented by the output of sensor S1. The result of this comparison is evaluated at step 409 to determine whether the output of sensor S1 identifies a doubling of bills for the particular denomination of bill determined at step 10 401. If the answer is negative, the system returns to the main program. If the answer is affirmative, step 410 then compares the retrieved density comparison value to the average density represented by the output of the second sensor S2. The result of this comparison is evaluated at step 411 to determine whether the output of sensor S2 identifies a doubling of bills. Affirmative answers at both step 409 and step 411 results 15 in the setting of a "doubles error" flag at step 412, and the system then returns to the main program. The above doubles detection routine is described in more detail in United States Patent No. 5,295,196 which is incorporated herein by reference. While the routine described above uses second characteristic information (density) to detect doubles, the above routine may be modified to authenticate bills based on their density, for example in 20 a manner similar to that described in connection with Table 1.

Referring now to FIGs. 8a-8c, there is shown a side view of a preferred embodiment of a document authenticating system according to the present invention, a top view of the preferred embodiment of FIG. 8a along the direction 8b, and a top view of the preferred embodiment of FIG. 8a along the direction 8c, respectively. An 25 ultraviolet ("UV") light source 802 illuminates a document 804. Depending upon the characteristics of the document, ultraviolet light may be reflected off the document and/or fluorescent light may be emitted from the document. A detection system 806 is positioned so as to receive any light reflected or emitted toward it but not to receive any UV light directly from the light source 802. The detection system 806 comprises a UV 30 sensor 808, a fluorescence sensor 810, filters, and a plastic housing. The light source 802 and the detection system 806 are both mounted to a printed circuit board 812. The

- document 804 is transported in the direction indicated by arrow A by a transport system (not shown). The document is transported over a transport plate 814 which has a rectangular opening 816 in it to permit passage of light to and from the document. In a preferred embodiment of the present invention, the rectangular opening 816 is 1.375
- 5 inches (3.493 cm) by 0.375 inches (0.953 cm). To minimize dust accumulation onto the light source 802 and the detection system 806 and to prevent document jams, the opening 816 is covered with a transparent UV transmitting acrylic window 818. To further reduce dust accumulation, the UV light source 802 and the detection system 806 are completely enclosed within a housing (not shown) comprising the transport plate 814.
- 10 Referring now to FIG. 9, there is shown a functional block diagram illustrating a preferred embodiment of a document authenticating system according to the present invention. FIG. 9 shows an UV sensor 902, a fluorescence sensor 904, and filters 906, 908 of a detection system such as the detection system 806 of FIG. 1. Light from the document passes through the filters 906, 908 before striking the sensors 902, 904,
- 15 respectively. An ultraviolet filter 906 filters out visible light and permits UV light to be transmitted and hence to strike UV sensor 902. Similarly, a visible light filter 908 filters out UV light and permits visible light to be transmitted and hence to strike fluorescence sensor 904. Accordingly, UV light, which has a wavelength below 400 nm, is prevented from striking the fluorescence sensor 904 and visible light, which has a wavelength
- 20 greater than 400 nm, is prevented from striking the UV sensor 902. In a preferred embodiment the UV filter 906 transmits light having a wavelength between about 280 nm and about 380 nm and has a peak transmittance at 360 nm. In a preferred embodiment, the visible light filter 908 is a blue filter and preferably transmits light having a wavelength between about 415 nm and about 620 nm and has a peak
- 25 transmittance at 450 nm. The above preferred blue filter comprises a combination of a blue component filter and a yellow component filter. The blue component filter transmits light having a wavelength between about 320 nm and about 620 nm and has a peak transmittance at 450 nm. The yellow component filter transmits light having a wavelength between about 415 nm and about 2800 nm. Examples of suitable filters are
- 30 UG1 (UV filter), BG23 (blue bandpass filter), and GG420 (yellow longpass filter), all

manufactured by Schott. In a preferred embodiment the filters are about 8 mm in diameter and about 1.5 mm thick.

The UV sensor 902 outputs an analog signal proportional to the amount of light incident thereon and this signal is amplified by amplifier 910 and fed to a microcontroller 912. Similarly, the fluorescence sensor 904 outputs an analog signal proportional to the amount of light incident thereon and this signal is amplified by amplifier 914 and fed to a microcontroller 912. Analog-to-digital converters 916 within the microcontroller 912 convert the signals from the amplifiers 910, 914 to digital and these digital signals are processed by the software of the microcontroller 912. The UV sensor 902 may be, for example, an ultraviolet enhanced photodiode sensitive to light having a wavelength of about 360 nm and the fluorescence sensor 904 may be a blue enhanced photodiode sensitive to light having a wavelength of about 450 nm. Such photodiodes are available from, for example, Advanced Photonix, Inc., Massachusetts. The microcontroller 912 may be, for example, a Motorola 68HC16.

The exact characteristics of the sensors 902, 904 and the filters 906, 908 including the wavelength transmittance ranges of the above filters are not as critical to the present invention as the prevention of the fluorescence sensor from generating an output signal in response to ultraviolet light and the ultraviolet sensor from generating an output signal in response to visible light. For example, instead of, or in addition to, filters, a authentication system according to the present invention may employ an ultraviolet sensor which is not responsive to light having a wavelength longer than 400 nm and/or a fluorescence sensor which is not responsive to light having a wavelength shorter than 400 nm.

Calibration potentiometers 918, 920 permit the gains of amplifiers 910, 914 to be adjusted to appropriate levels. Calibration may be performed by positioning a piece of white fluorescent paper on the transport plate 814 so that it completely covers the rectangular opening 816 of FIG. 1. The potentiometers 918, 920 may then be adjusted so that the output of the amplifiers 910, 914 is 5 volts. Alternatively, calibration may be performed using genuine currency such as a piece of genuine U.S. currency. Potentiometers 918 and 920 may be replaced with electronic potentiometers located, for example, within the microcontroller 912. Such electronic potentiometers may permit

automatic calibration based on the processing of a single genuine document or a plurality of documents as will be described below.

The implementation of a preferred embodiment of a document authenticating system according to the present invention as illustrated in FIG. 9 will hereinafter be described with respect to the authentication of U.S. currency. However, it will be appreciated that the system may also be used to authenticate foreign currency or other types of documents in which reflectance and fluorescence characteristics of genuine documents are known.

It has been determined that genuine United States currency reflects a relatively high amount of ultraviolet light, e.g. above a minimum UV threshold value, and does not fluoresce under ultraviolet illumination. A currency bill under test may thereby be rejected as counterfeit if it reflects an amount of UV light less than the minimum UV threshold value or fluoresces under ultraviolet illumination. However, it has been determined that some counterfeit bills may reflect an even higher amount of ultraviolet light than genuine United States currency. Accordingly, in a preferred embodiment, the authentication system according to the present invention compares the amount of reflected ultraviolet light from a currency bill under test to a maximum UV threshold value as well as a minimum UV threshold value. A currency bill under test will thereby be classified as genuine only if it reflects an amount of ultraviolet light greater than the minimum UV threshold and less than the maximum UV threshold, e.g. within an acceptable range of values defined between a minimum and maximum UV threshold. Additionally, the system may be designed to detect fluorescence levels in order to reject bills which fluoresce in response to being illuminated with ultraviolet light.

Under ultraviolet illumination, counterfeit bills under test will exhibit one of the six sets of characteristics listed below:

- 1) Reflects below the minimum level of ultraviolet light and fluoresces;
- 2) Reflects below the minimum level of ultraviolet light and does not fluoresce;
- 3) Reflects an intermediate level of ultraviolet light and fluoresces;
- 4) Reflects an intermediate level of ultraviolet light and does not fluoresce;
- 5) Reflects higher than the maximum level of ultraviolet light and fluoresces;

- 6) Reflects higher than the maximum level of ultraviolet light and does not fluoresce.

- Counterfeit bills in categories (1), (2), (5) and (6) may be detected by a currency authenticator employing an ultraviolet light reflection test according to a preferred embodiment of the present invention. Counterfeit bills in category (3) may be detected by a currency authenticator employing both an ultraviolet reflection test and a fluorescence test according to another preferred embodiment of the present invention. Only counterfeit bills in category (4) are not detected by the authenticating methods of the present invention.
- 10 As indicated above, genuine United States currency does not fluoresce under ultraviolet illumination. It has also been determined that British currency does not fluoresce under ultraviolet illumination. According to a preferred embodiment of the present invention, fluorescence is determined by any signal that is above the noise floor. Thus, the amplified fluorescent sensor signal 922 will be approximately 0 volts for
- 15 genuine U.S. or British currency and will vary between approximately 0 and 5 volts for counterfeit bills depending upon their fluorescent characteristics. Accordingly, an authenticating system according to a preferred embodiment of the present invention will reject bills when signal 922 exceeds approximately 0 volts.
- According to a preferred embodiment of the present invention, a low level of
- 20 reflected UV light ("low" UV) is indicated when the amplified UV sensor signal 924 is below a predetermined minimum UV threshold. Conversely, a high level of reflected UV light ("high UV") is indicated when the amplified UV sensor signal 924 is above a predetermined maximum UV threshold. The value of the amplified UV sensor signal 924 is a function of lamp intensity and reflectance. Lamp intensity can degrade by as
- 25 much as 50% over the life of the lamp and can be further attenuated by dust accumulation on the lamp and the sensors. The problem of dust accumulation is mitigated by enclosing the lamp and sensors in a housing as discussed above. An authenticating system according to a preferred embodiment of the present invention tracks the intensity of the UV light source and readjusts the minimum and maximum UV
- 30 thresholds accordingly. The degradation of the UV light source may be compensated for by periodically feeding a genuine bill into the system, sampling the output of the UV

sensor, and adjusting the thresholds accordingly. Alternatively, degradation may be compensated for by periodically sampling the output of the UV sensor when no bill is present in the rectangular opening 816 of the transport plate 814. It is noted that a certain amount of UV light is always reflected off the acrylic window 818. By periodically 5 sampling the output of the UV sensor when no bill is present, the system can compensate for light source degradation. Furthermore, such sampling could also be used to indicate to the operator of the system when the ultraviolet light source has burned out or otherwise requires replacement. This may be accomplished, for example, by means of a display reading or an illuminated light emitting diode ("LED"). The amplified ultraviolet 10 sensor signal 924 will initially vary between 1.0 and 5.0 volts depending upon the UV reflectance characteristics of the document being scanned and will slowly drift downward as the light source degrades. In an alternative preferred embodiment to a preferred embodiment wherein the threshold level is adjusted as the light source degrades, the sampling of the UV sensor output may be used to adjust the gain of the amplifier 910 15 thereby maintaining the output of the amplifier 910 at its initial levels.

In one embodiment of the present invention, the maximum and minimum UV thresholds are set at approximately 50% above and below the expected value of a genuine United States bill. For example, if a genuine U.S. bill generates an amplified UV output sensor signal 924 of 4.0 volts, the minimum threshold value is set at 2.0 volts 20 and the maximum threshold value is set at 6.0 volts. Documents generating an amplified UV output sensor signal 924 of 2.0 volts or less will thereby be rejected as counterfeit, as will those generating an amplified UV output sensor signal 924 of 6.0 volts or higher. As described above, the upper and lower thresholds may either be lowered as the light source degrades or the gain of the amplifier 910 may be adjusted so that the upper and 25 lower thresholds remain at approximately 50% above and below the amplified UV output sensor signal 924 of a genuine bill.

In an alternative embodiment, the determination of whether the level of UV reflected off a document is above or below a given threshold may be made by sampling the output of the UV sensor at a number of intervals, averaging the readings, and 30 comparing the average level with the appropriate threshold level. Alternatively, a comparison may be made by measuring the amount of UV light reflected at a number of

- locations on the bill and comparing these measurements with those obtained from genuine bills. Alternatively, the output of one or more UV sensors may be processed to generate one or more patterns of reflected UV light and these patterns may be compared to the patterns generated by genuine bills. Such a pattern generation and comparison
- 5 technique may be performed by modifying an optical pattern technique such as that disclosed in United States Pat. No. 5,295,196 incorporated herein by reference in its entirety or in United States patent application Serial No. 08/287,882 filed August 9, 1994 for a "Method and Apparatus for Document Identification," incorporated herein by reference in its entirety.
- 10 In a similar manner, the presence of fluorescence may be performed by sampling the output of the fluorescence sensor at a number of intervals. With respect to either U.S. or British currency, a bill is rejected as counterfeit if any of the sampled outputs rise above the noise floor. However, alternative methods may be employed with respect to currencies of other countries or other types of documents which may employ as security
- 15 features certain locations or patterns of fluorescent materials.

A currency authenticating system according to the present invention may be provided with means, such as a display, to indicate to the operator the reasons why a document has been rejected, e.g., messages such as "UV FAILURE" or "FLUORESCENCE FAILURE." A currency authenticating system according to the

20 present invention may also permit the operator to selectively choose to activate or deactivate either the UV reflection test or the fluorescence test or both. A currency authenticating system according to the present invention may also be provided with means for adjusting the sensitivities of the UV reflection and/or fluorescence test, for example, by adjusting the respective thresholds. For example, a system according to the

25 present invention may permit the high/low threshold to be adjusted, for example, either in absolute voltage terms or in genuine/suspect ratio terms.

The UV and fluorescence authentication test may be incorporated into various document handlers such as currency counters and/or currency denomination discriminators such as that disclosed in connection with FIG. 4 and U.S. Patent No.

30 5,295,196 incorporated herein by reference in its entirety. Likewise, the magnetic authentication tests described above may likewise be incorporated in such counters

and/or discriminators. In such systems, calibration may be performed by processing a stack of genuine documents. An example of a method of calibrating such a device will now be discussed.

- As mentioned above, the acrylic window 818 reflects a certain amount of UV light even when no bill is present. The amount of UV light reflected in the absence of bills is measured. A stack of genuine bills may then be processed with the potentiometer 918 set to some arbitrary value and the resulting UV readings averaged. The difference between the average reading and the reading made in the absence of bills may then be calculated. The potentiometer 918 may then be adjusted so that the average reading would be at least 0.7 volts greater than the no bill reading. It is also desirable to adjust the potentiometer 918 so that the amplifier 910 operates around the middle of its operating range. For example, if a reading of 1.0 volt results when no bills are present and an average reading of 3.0 volts results when a stack of genuine bills are processed, the resulting difference is 2.0 volts which is greater than 0.7 volts. However, it is desirable for the amplifier to be operating in the range of about 2.0 to 2.5 volts and preferably at about 2.0 volts. Thus in the above example, the potentiometer 918 may be used to adjust the gain of the amplifier 910 so that an average reading of 2.0 volts would result. When potentiometer 918 is an electronic potentiometer, the gain of the amplifier 910 may be automatically adjusted by the microcontroller 912. In general, when the average reading is too high the potentiometer is adjusted to lower the resulting values to the center of the operating range of the amplifier and vice versa when the average reading is too low.

- According to another embodiment of the present invention, the operator of a document handling device such as a currency counter or a currency denomination discriminator is provided with the ability to adjust the sensitivity of a UV reflection test, a fluorescence test, and a magnetic test. For example, a note counter embodying a preferred embodiment of the present invention may provide the operator the ability to set the authentication tests to a high or a low sensitivity. For example, the note counter may be provided with a set up mode which enables the operator to adjust the sensitivities for each of the above tests for both the high and the low modes. This may be achieved through appropriate messages being displayed on, for example, display 82 of FIG. 4 and

the input of selection choices via an input device such as a keyboard or buttons. In one embodiment, the device permits the operator to adjust the UV test, the fluorescent test, and the magnetic test in a range of sensitivities 1 - 10, with 10 being the most sensitive, or to turn each test off. The device permits setting the sensitivity as described above for

- 5 the three authentication tests for both a low sensitivity (low denomination) mode and a high sensitivity (high denomination) mode. The above setting options are summarized in Table 2.

Table 2

Mode	UV Test -- Lower Sensitivity	UV Test -- Upper Sensitivity	Fluorescent Test Sensitivity	Magnetic Test Sensitivity
High	Off, 1-10	Off, 1-10	Off, 1-10	Off, 1-10
Low	Off, 1-10	Off, 1-10	Off, 1-10	Off, 1-10
1,2,5,10,20,50,100	Off, 1-10	Off, 1-10	Off, 1-10	Off, 1-10

According to an alternate embodiment, the above high/low modes are replaced

- 10 with denomination modes, for example, one for each of several denominations of currency (e.g., \$1, \$2, \$5, \$10, \$20, \$50 and \$100). For each denomination, the sensitivity of the three tests may be adjusted between 1-10 or off. According to one embodiment for operator manually selects either the high or low mode or the appropriate denomination mode based on the values of the notes to be processed. This manual mode
15 selection system may be employed in, for example, either a note counter or a currency denomination discriminator. According to another embodiment the document handling system automatically selects either the high or low mode or the appropriate denomination mode based on the values of the notes being processed. This automatic mode selection system may be employed in systems capable of identifying the different values or kinds
20 of documents, for example, a currency denomination discriminator.

Accordingly, in the low mode or for low denomination modes (e.g., \$1, \$2) the three tests may be set to relatively low sensitivities (e.g., UV test set at 2, fluorescent test set at 5, and magnetic test set at 3). Conversely, in the high mode or for high denomination modes (e.g., \$50, \$100) the three tests may be set to relatively high

sensitivities (e.g., UV test set at 5, fluorescent test set at 6, and magnetic test set at 7). In this way, authentication sensitivity may be increased when processing high value notes where the potential harm or risk in not detecting a counterfeit may be greater and may be decreased when processing low value notes where the potential harm or risk in not

- 5 detecting a counterfeit is lesser and the annoyance of wrongly rejecting genuine notes is greater. Also the UV, fluorescent, and/or magnetic characteristics of genuine notes can vary due to number of factors such wear and tear or whether the note has been washed (e.g., detergents). As a result, the fluorescent detection of genuine U.S. currency, for example, may yield readings of about 0.05 or 0.06 volts.

- 10 With respect to U.S. currency, the UV and fluorescent thresholds associated with each of the ten sensitivity levels may be set, for example, as shown in Table 3.

Table 3

Sensitivity Level	UV Test -- Lower (Volts)	UV Test -- Upper (Volts)	Fluorescence Test (Volts)
1	0.200	2.200	0.800
2	0.325	2.100	0.600
3	0.450	2.000	0.400
4	0.550	1.900	0.200
5	0.600	1.800	0.150
6	0.650	1.700	0.100
7	0.700	1.600	0.090
8	0.750	1.500	0.080
9	0.800	1.450	0.070
10	0.850	1.400	0.060

Although the UV and fluorescence threshold values associated with sensitivity levels 1-10 in Table 3 are derived with respect to U.S. currency, it will be appreciated

that the sensitivity levels may be appropriately selected to authenticate foreign currency or other documents having known reflectance characteristics.

- In performing the UV test according to one embodiment, the no bill reflectance value is subtracted from resulting UV reflectance voltages associated with the scanning 5 of a particular bill, and this difference is compared against the appropriate threshold value such as those in Table 3 in determining whether to reject a bill.

According to one embodiment, the potentiometer 920 associated with the fluorescence detector 204 is calibrated by processing a genuine note or stack of notes, as described above in connection with the calibration of the UV detector, and adjusted so 10 that a reading of near 0 volts (e.g., about 0.1 volt) results. Magnetic calibration may be performed, for example, manually in conjunction with the processing of a genuine bill of known magnetic characteristics and adjusting the magnetic sensor to near the center of its range.

Upon a bill failing one or more of the above tests, an appropriate error message 15 may be displayed such as "Suspect Document U--" for failure of the UV reflection test, "Suspect Document -F-" for failure of the fluorescent test, "Suspect Document --M" for failure of the magnetic test, or some combination thereof when more than one test is failed (e.g., "Suspect Document UF--" for failure of both the UV reflection test and the fluorescent test).

20 While the present invention has been described with reference to one or more particular embodiments, those skilled in the art will recognize that many changes may be made thereto without departing from the spirit and scope of the present invention, which is set forth in the following claims.

CLAIMS:

What is claimed is:

1. A method of authenticating documents comprising the steps of:
 - illuminating a document with ultraviolet light;
 - detecting ultraviolet light reflected by said document; and
 - determining the authenticity of said document based upon a comparison of the ultraviolet light reflected from said bill with a minimum threshold value and a maximum threshold value, said minimum and maximum threshold values being predetermined relative to the ultraviolet light reflected from a genuine document illuminated with ultraviolet light, wherein a negative determination of authenticity is made regarding said document if an amount of ultraviolet light reflected from said document is below said minimum threshold value or above said maximum threshold value.
2. The method of claim 1 wherein the determination of authenticity of said document is determined relative to genuine British currency.
3. The method of claim 2 wherein said minimum threshold value is one-half an amount of ultraviolet light expected to be detected from a genuine British bill and wherein said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine British bill.
4. The method of claim 3 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a negative determination of authenticity is made if the voltage generated by said step of detecting ultraviolet light reflected by said document is less than or equal to one-half a voltage expected for a genuine British bill or greater than or equal to one and one-half the voltage expected for a genuine British bill.
5. The method of claim 1 wherein the determination of authenticity of said document is determined relative to genuine United States currency.
6. The method of claim 5 wherein said minimum threshold value is one-half an amount of ultraviolet light expected to be detected from a genuine U.S. bill and wherein said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine U.S. bill.

7. The method of claim 6 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a negative determination of authenticity is made if the voltage generated by said step of detecting 5 ultraviolet light reflected by said document is less than or equal to one-half a voltage expected for a genuine U.S. bill or greater than or equal to one and one-half the voltage expected for a genuine U.S. bill.

8. The method of claim 1 further comprising the step of detecting the amount of visible light emitted from said document and wherein a negative determination of 10 authenticity is made regarding said document if the amount of visible light emitted from said document exceeds approximately zero volts.

9. The method of claim 1 wherein said step of detecting ultraviolet light reflected by said document comprises taking a number of samples of amounts of ultraviolet light reflected by said document and averaging said samples to obtain an average and wherein 15 a negative determination of authenticity is made regarding said document if said average is below said minimum threshold value or above said maximum threshold value.

10. A method of authenticating documents comprising the steps of:
illuminating a document with ultraviolet light;
detecting the amount of ultraviolet light reflected from one or more areas of said 20 document; and

determining the authenticity of said document based upon a comparison of the ultraviolet light reflected from said bill with the ultraviolet light reflected from a genuine document illuminated with ultraviolet light, the determination of authenticity being made relative to genuine currency and wherein a positive determination of authenticity is made 25 regarding said document only if an amount of ultraviolet light reflected from said document exceeds a minimum threshold value and does not exceed a maximum threshold value.

11. The method of claim 10 wherein the determination of authenticity of said document is determined relative to genuine British currency.

30 12. The method of claim 11 wherein said minimum threshold value is one-half an amount of ultraviolet light expected to be detected from a genuine British bill and

wherein said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine British bill.

13. The method of claim 12 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a positive determination of authenticity is made if the voltage generated by said step of detecting ultraviolet light reflected by said document is greater than or equal to one-half a voltage expected for a genuine British bill and less than or equal to one and one-half the voltage expected for a genuine British bill.
- 10 14. The method of claim 10 wherein the determination of authenticity of said document is determined relative to genuine United States currency.
15. The method of claim 14 wherein said minimum threshold value is one-half an amount of ultraviolet light expected to be detected from a genuine U.S. bill and wherein said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine U.S. bill.
- 20 16. The method of claim 15 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a positive determination of authenticity is made if the voltage generated by said step of detecting ultraviolet light reflected by said document is greater than or equal to one-half a voltage expected for a genuine U.S. bill and less than or equal to one and one-half the voltage expected for a genuine U.S. bill.
- 25 17. The method of claim 10 further comprising the step of detecting the amount of visible light emitted from said document and wherein a positive determination of authenticity is made regarding said document only if the amount of ultraviolet light reflected from said document exceeds a minimum threshold value and does not exceed a maximum threshold value and the amount of visible light emitted from said document does not exceed approximately zero volts.
- 30 18. The method of claim 10 wherein said step of detecting ultraviolet light reflected by said document comprises taking a number of samples of amounts of ultraviolet light reflected by said document and averaging said samples to obtain an

average and wherein a positive determination of authenticity is made regarding said document if said average is above said minimum threshold value and below said maximum threshold value.

19. A device for authenticating documents comprising:
 - 5 an ultraviolet light source for illuminating a document to be tested;
 - an ultraviolet light detector for generating an output signal responsive to the amount of ultraviolet light reflected from one or more areas of said document; and
 - a signal processor for receiving said ultraviolet detector output signal and determining the authenticity of said document based upon a comparison of said output
- 10 signal to a minimum threshold value and a maximum threshold value, wherein a negative determination of authenticity is made regarding said document if an amount of ultraviolet light reflected from said document is below said minimum threshold value or above said maximum threshold value.
20. The device of claim 19 wherein the determination of authenticity of said
- 15 document is determined relative to genuine British currency.
21. The device of claim 20 wherein said minimum threshold value is one-half an amount of ultraviolet light expected to be detected from a genuine British bill and wherein said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine British bill.
- 20 22. The device of claim 21 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a negative determination of authenticity is made if the voltage generated by said step of detecting ultraviolet light reflected by said document is less than or equal to one-half a voltage
- 25 expected for a genuine British bill or greater than or equal to one and one-half the voltage expected for a genuine British bill.
23. The device of claim 19 wherein the determination of authenticity of said document is determined relative to genuine United States currency.
24. The device of claim 23 wherein said minimum threshold value is one-half an
- 30 amount of ultraviolet light expected to be detected from a genuine U.S. bill and wherein

said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine U.S. bill.

25. The device of claim 23 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a negative determination of authenticity is made if the voltage generated by said step of detecting ultraviolet light reflected by said document is less than or equal to one-half a voltage expected for a genuine U.S. bill or greater than or equal to one and one-half the voltage expected for a genuine U.S. bill.

- 10 26. The device of claim 19 further comprising a visible light detector for generating an output signal responsive to the amount of visible light emitted from said document upon illumination of said document by said ultraviolet light source, wherein said signal processor receives the visible light detector output signal and determines the authenticity of said document based upon said visible light detector output signal,
- 15 wherein a negative determination of authenticity is made regarding said document if said visible light detector output signal exceeds approximately zero volts.

27. The device of claim 19 wherein said ultraviolet light detector takes a number of samples of amounts of ultraviolet light reflected by said document and generates a number of output signals; wherein said signal processor averages said number of output signals to obtain an average and wherein a negative determination of authenticity is made regarding said document if said average is below said minimum threshold value or above said maximum threshold value.

28. A device for authenticating documents comprising:
an ultraviolet light source for illuminating a document to be tested;
25 an ultraviolet light detector for generating an output signal responsive to the amount of ultraviolet light reflected from one or more areas of said document; and
a signal processor for receiving said ultraviolet detector output signal and determining the authenticity of said document based upon a comparison of said output signal to a minimum threshold value and a maximum threshold value, wherein a positive 30 determination of authenticity is made regarding said document only if an amount of

ultraviolet light reflected from said document is above said minimum threshold value and does not exceed said maximum threshold value.

29. The device of claim 28 wherein the determination of authenticity of said document is determined relative to genuine British currency.

5 30. The device of claim 29 wherein said minimum threshold value is one-half an amount of ultraviolet light expected to be detected from a genuine British bill and wherein said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine British bill.

10 31. The device of claim 30 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a positive determination of authenticity is made if the voltage generated by said step of detecting ultraviolet light reflected by said document exceeds one-half a voltage expected for a genuine British bill and does not exceed one and one-half the voltage expected for a 15 genuine British bill.

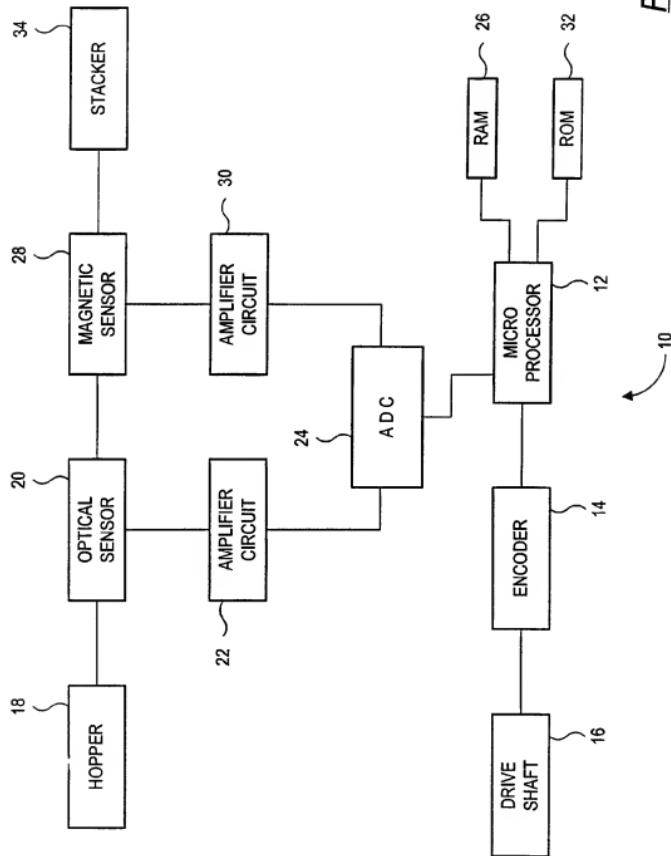
32. The device of claim 28 wherein the determination of authenticity of said document is determined relative to genuine United States currency.

20 33. The device of claim 32 wherein said minimum threshold value is one-half an amount of ultraviolet light expected to be detected from a genuine U.S. bill and wherein said maximum threshold value is one and one-half the amount of ultraviolet light expected to be detected from a genuine U.S. bill.

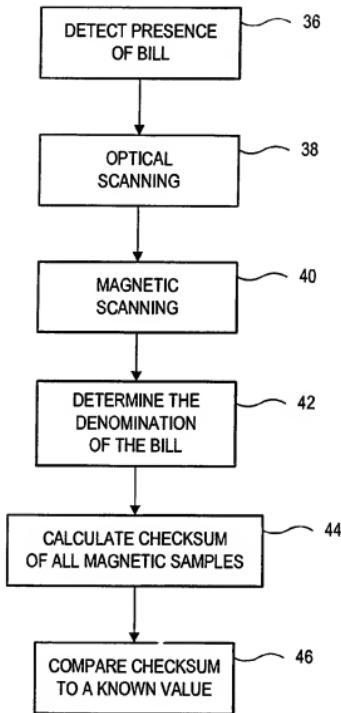
25 34. The device of claim 33 wherein a detector is used for said step of detecting ultraviolet light reflected by said document; wherein said detector generates an output voltage based on the amount of ultraviolet light detected; and wherein a positive determination of authenticity is made if the voltage generated by said step of detecting ultraviolet light reflected by said document exceeds one-half a voltage expected for a genuine U.S. bill and does not exceed one and one-half the voltage expected for a 30 genuine U.S. bill.

35. The device of claim 28 further comprising a visible light detector for generating an output signal responsive to the amount of visible light emitted from said document upon illumination of said document by said ultraviolet light source, wherein

- said signal processor receives the visible light detector output signal and the ultraviolet detector signal and determines the authenticity of said document based upon said visible light detector output signal and the ultraviolet detector signal, wherein a positive determination of authenticity is made regarding said document only if the amount of
- 5 ultraviolet light reflected from said document is above said minimum threshold value and does not exceed said maximum threshold value and said visible light detector output signal does not exceed approximately zero volts.
36. The device of claim 28 wherein said ultraviolet light detector takes a number of samples of amounts of ultraviolet light reflected by said document and generates a
- 10 number of output signals; wherein said signal processor averages said number of output signals to obtain an average and wherein a positive determination of authenticity is made regarding said document if said average is above said minimum threshold value and below said maximum threshold value.



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*FIG. 2*

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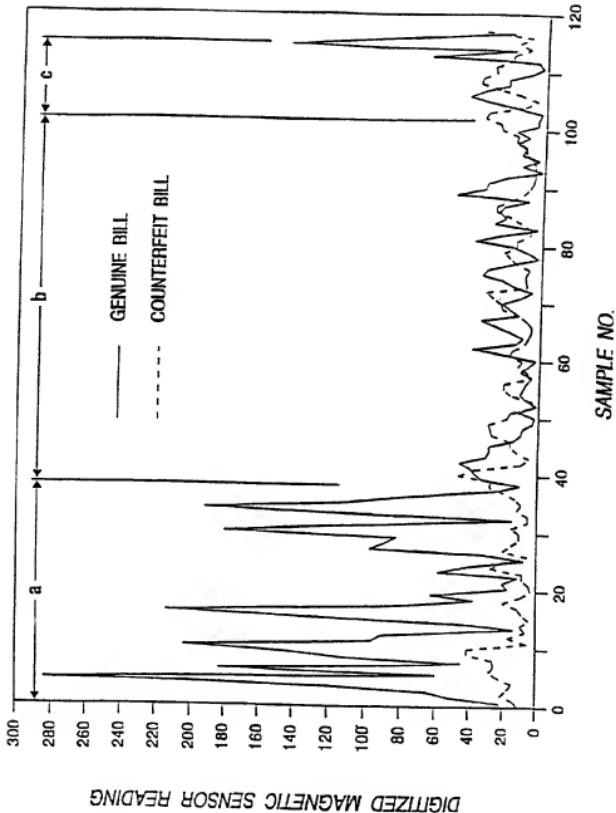
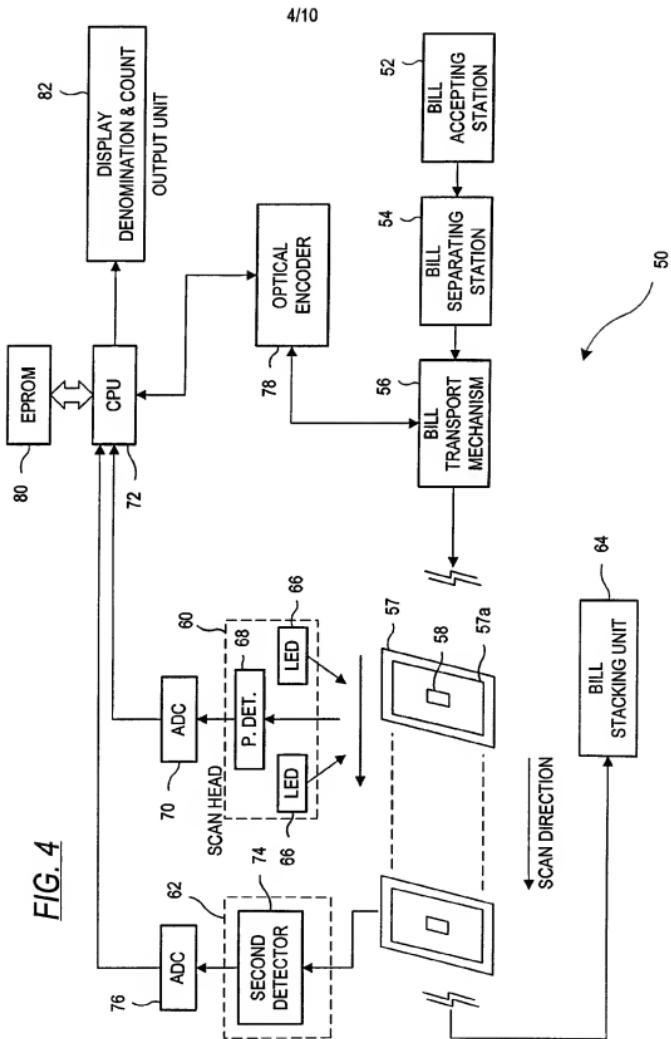
FIG. 3

FIG. 4



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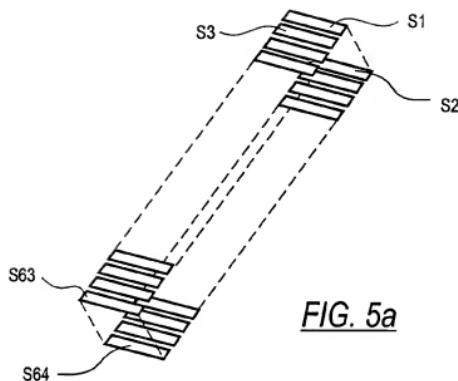


FIG. 5a

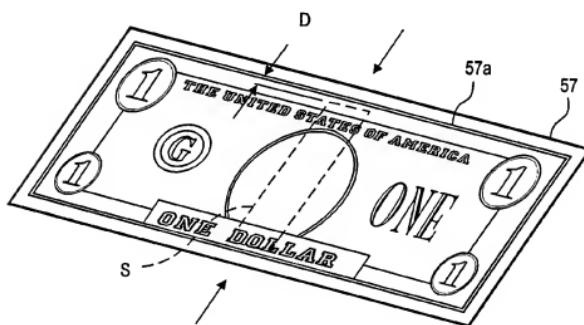


FIG. 5b

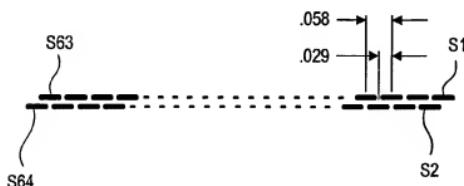


FIG. 5c

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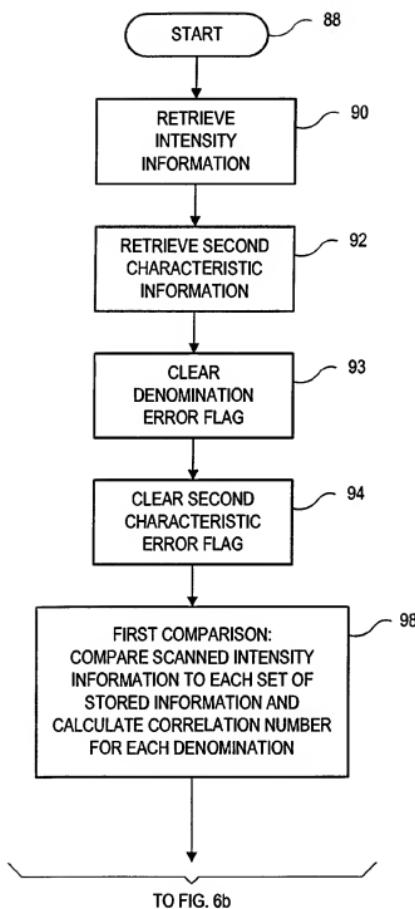


FIG. 6a

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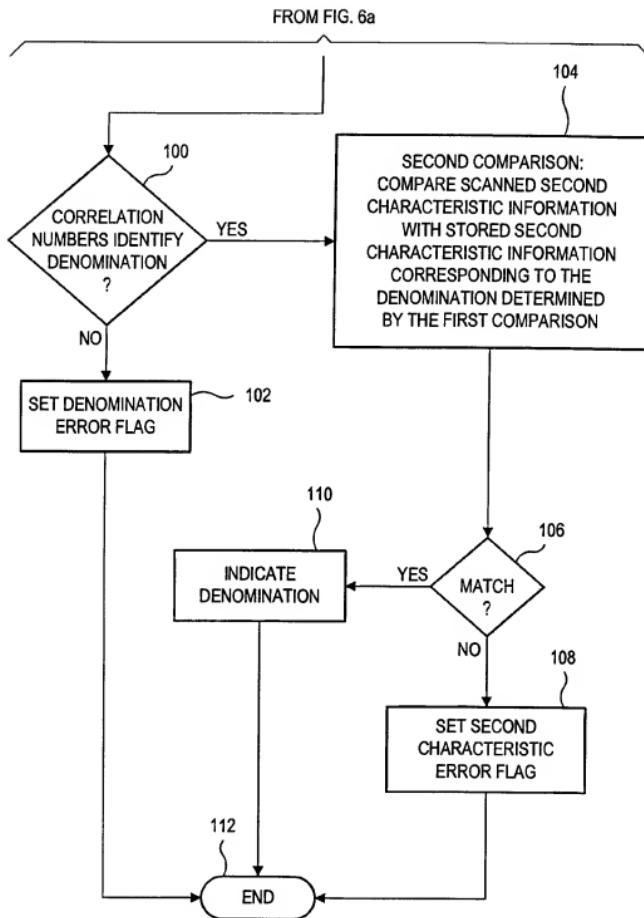


FIG. 6b

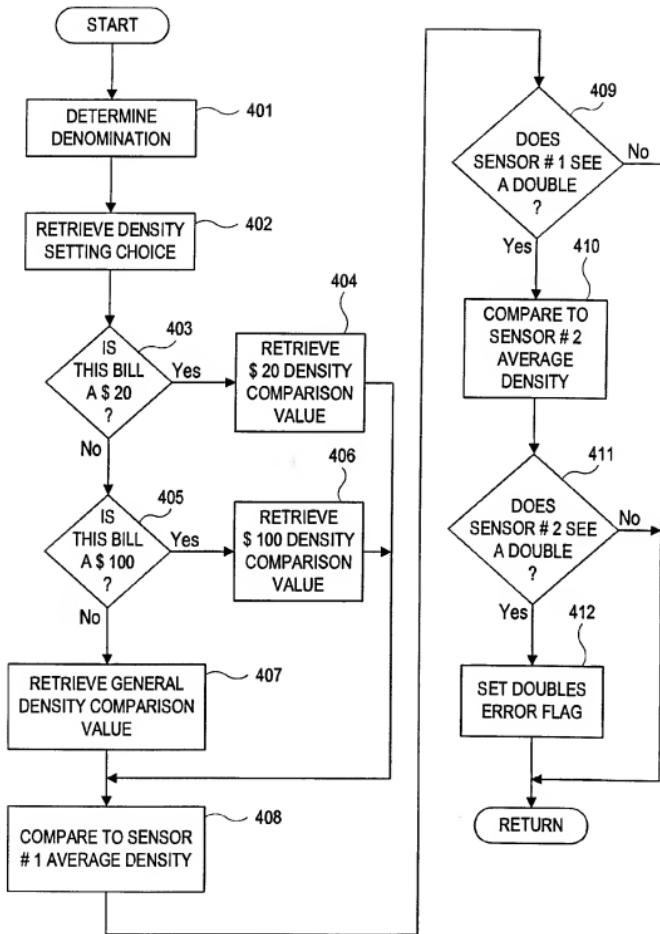


FIG. 7

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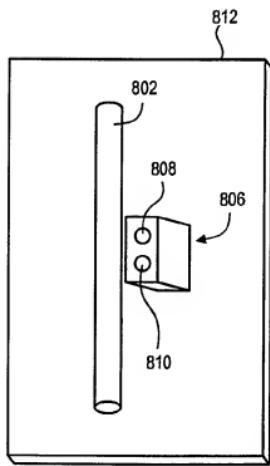
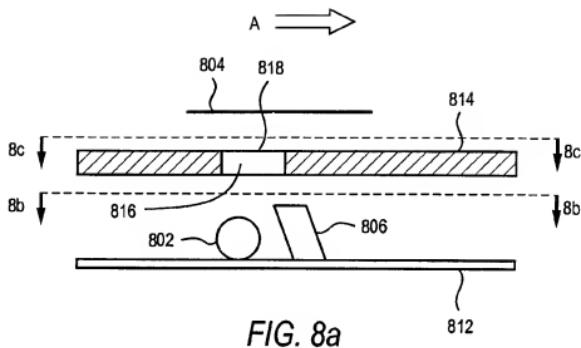


FIG. 8b

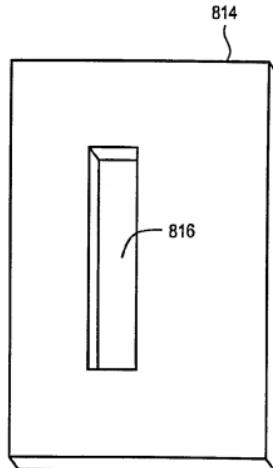
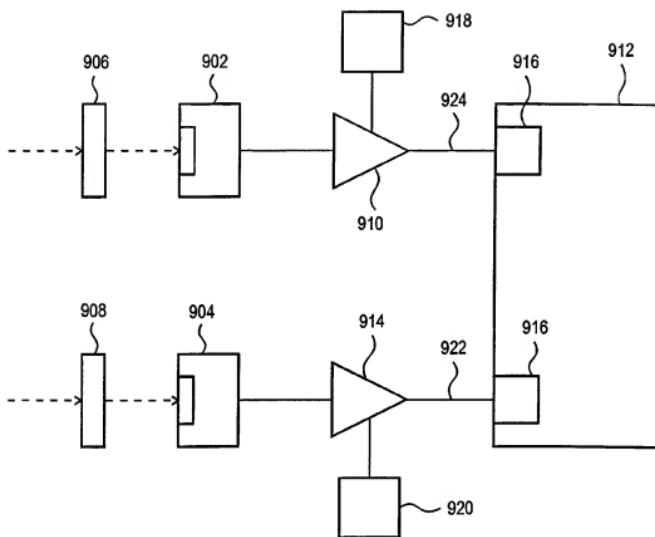


FIG. 8c

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*FIG. 9*